APPLICATION

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APPENDIX 2

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The Jet Pump

One practical use of the fluid jet is to pump fluids to a higher pressure by use of a jet of fluid injected into a pipe of moving fluid. Such a *jet pump* is illustrated in figure 5.6 which shows a jet of velocity V_s and area A_s aligned with the axis of a pipe of area A at a point where the pipe flow velocity is V_1 and the pressure is p_1. At a distance downstream, where the two streams have completely mixed, the velocity is V_2, and the pressure p_2 is greater than p_1. The amount of the pressure rise $p_2 - p_1$ depends upon the velocities V_1 and V_s and the area ratio A_s/A in a manner that may be found by applying mass and momentum conservation to the fluid in the control volume shown in figure 5.6.

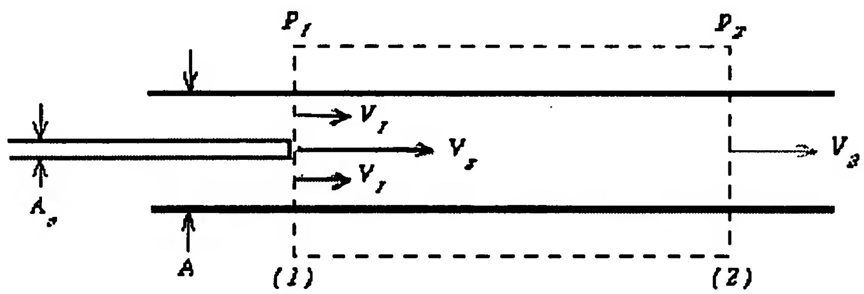

Figure 5.6: A jet pump consists of a coaxial jet of high speed fluid injected into a pipe of lower speed fluid. The mixing of the two streams produces a rise in pressure downstream.

We will consider the case for which the jet fluid and the pumped fluid are both incompressible and have the same density ρ. Applying mass conservation to the steady flow of fluid across the control surface of figure 5.6,

$$\rho A V_2 = \rho(A - A_s)V_1 + \rho A_s V_s$$

Next use the linear momentum equation 5.11 for the same control volume, but assume that the viscous force on the pipe walls is negligible ($\tau = 0$):

$$\frac{d}{dt}\iiint_{\mathcal{V}} \rho\mathbf{V}\, d\mathcal{V} + (\dot{m}\mathbf{V})_{out} - (\dot{m}\mathbf{V})_{in}$$
$$= \iint_{S}(-p\mathbf{n})\, dS + \iint_{S} dS + \iiint_{\mathcal{V}} \rho\mathbf{g}\, d\mathcal{V} + \Sigma\mathbf{F}_{ex}$$
$$0 + \rho A V_2^2 - \rho(A - A_e)V_1^2 - \rho A_e V_e^2$$
$$= (p_1 - p_2)A + 0 + 0 + 0$$

Eliminating V_2 between these two equations and solving for the pressure rise,

$$p_2 - p_1 = \frac{A_e}{A}\left(1 - \frac{A_e}{A}\right)\rho(V_e - V_1)^2 \qquad (5.24)$$

The maximum pressure rise that we could expect would be that for inviscid flow of the jet decelerating from the speed V_e to $V_2 = V_e A_e / A$, or a pressure rise of $(\rho V_e^2/2)(1 - A_e^2/A^2)$. Dividing equation 5.24 by this pressure rise, we have a dimensionless form of the jet pump equation:

$$\frac{p_1 - p_2}{\frac{1}{2}\rho V_e^2\left[1 - (A_e/A)^2\right]} = 2\left(\frac{A_e/A}{1 + A_e/A}\right)\left(1 - \frac{V_1}{V_e}\right)^2 \qquad (5.25)$$

Since $A_e/A \leq 1$ and $V_1/V_e \leq 1$, the right side of equation 5.25 is always less than one.

The jet pump allows us to pump a greater volume flow rate ($V_1[A - A_e]$) than that needed to supply the jet ($V_e A_e$), albeit with a lower pressure rise than that needed for the jet supply.

Example 5.12

A jet pump consists of a jet of diameter $D_s = 1\,in$ inside a pipe of diameter $D = 3\,in$. The jet volumetric flow rate Q_s is $100\,GPM$ (gallons per minute). Calculate the pressure rise in the jet pump when the volumetric flow rate Q_1 is $500\,GPM$.

Solution

In SI units, the flow areas and flow rates are:

$$A_s = \frac{\pi}{4}(2.54E(-2)\,m)^2 = 5.067E(-4)\,m^2; \qquad A = 9A_s = 4.560E(-3)\,m^2$$

$$Q_s = \frac{100\,gal}{min} \times \frac{3.785E(-3)\,m^3}{gal} \times \frac{min}{60\,s} = 6.308E(-3)\,m^3/s;$$

$$Q_1 = 5\,Q_s = 3.154E(-2)\,m^3/s$$

and the velocities V_1 and V_s are:

$$V_1 = \frac{Q_1}{A - A_s} = \frac{3.154E(-2)\,m^3/s}{4.560E(-3)\,m^2 - 5.067E(-4)\,m^2} = 7.781\,m/s$$

$$V_s = \frac{Q_s}{A_s} = \frac{6.308E(-3)\,m^3/s}{5.067E(-4)\,m^2} = 12.45\,m/s$$

Substituting these values in equation 5.24,

$$p_2 - p_1 = \frac{1}{9}\left(1 - \frac{1}{9}\right)(1E(3)\,kg/m^3)(12.45\,m/s - 7.781\,m/s)^2 = 2.153E(3)\,Pa$$

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